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Assessment of digital transformation challenges for business model innovation in the context of higher education institutions using a decision support approach

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A B S T R A C T

Higher education plays a central role in the current digital revolution. This sector is experiencing a constant process of digital transformation (DT) that is expected to produce substantial instabilities in the currently used business tools. However, the literature still lacks research investigating how the business tools are innovated from the perspective of "higher education institutions (HEIs)" while considering the impact of DT on this process. To deal with the concern, this paper identifies the major impressions of DT on the business model provided by HEIs, using means of a fuzzy decision-making tool. To this end, the current paper integrated three previously-proposed methods, i.e., the "intuitionistic fuzzy sets (IFSs)", the "method based on the removal effects of criteria (MEREC)", the "rank sum (RS)", and the "additive ratio assessment (ARAS)" into a new decision-making framework called IF-MEREC-RS-ARAS. In the proposed hybrid method, IF-MEREC-RS is responsible for computing the objective-subjective weighting of the key DT challenges that arise for "business model innovation (BMI)" in the perspective of HEIs. In addition, IF-ARAS evaluates the HEIs' preferences over various DT challenges for BMI in the context of HEIs. This research also involves an empirical case study for the assessment of the major DT challenges that arise for BMI in HEIs. To end, a number of comparisons and sensitivity discussions were carried out to compare the performance of the introduced model with that of other models. The findings confirmed the higher effectiveness of the developed model in terms of the tasks defined.

Introduction

Recent years have witnessed the digital transformation (DT) phenomenon as well as a great focus of the academic community on this subject (Fitzgerald et al., 2014; Kane et al., 2015). The DT, or "digitalization", refers to the process of combining business with digital technologies (Liu et al., 2011). With the use of "digital technology (DTL)", products and facilities could be well combined through organizational and geographic frontiers (Sebastian et al., 2017). Digital technologies, this way, accelerate the change and result in the transformation of many industrial sectors (Bharadwaj et al., 2013a; Ghezzi et al., 2015). This is due to the high capacity of these technologies to disrupt the present circumstances and driving technological change (Bharadwaj et al., 2013a). DTLs have led to a great revolution in how industries operate (Dal Mas et al., 2020). They have also resulted in the introduction of new concepts such as "Industry 4.0″ and "smart factory" (Lasi et al., 2014). For example, digital platforms help firms and organizations to operate within a "business ecosystem" (Presch et al., 2020). This has resulted in significant changes to the dynamics of assessment networks (Gray et al., 2015). Recently, DTLs have been successful in transforming both business (Ng & Wakenshaw, 2017) and society; they have brought fundamental variations over proposing innovative models such as circular and sharing economy.

By definition, "business model innovation (BMI)" is "designed, nontrivial changes to the key elements of a firm's business model and/or the architecture linking these elements" (Foss & Saebi, 2016). When it comes to digital BMI, the changes are driven by or embodied in digital technologies (Bican & Brem, 2020; Fichman et al., 2014; Teece, 2010). It has been generally recognized that companies are required to pursue BMI to experience a popular DT, though the literature still lacks adequate research on the nature of digital BMI. Rather, the literature is mostly concentrated on the external antecedences of

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BMI, e.g., big data analytics, IoT, family influence, or opportunity recognition. The study by Li (2020) investigated how digital technologies are applied to facilitate BMI in creative businesses. They emphasized the regions of business models that have been influenced by extension, automation, or transformation. Some other researchers have focused on the exploration of the definite types of BMIs driven by technology, for instance, digital platform business models (Kazan et al., 2018) or 3-D printing business models (Holzmann et al., 2020). Regardless of such recent developments in this domain, there is still a requirement for extra work on the way the BMIs of incumbent enterprises are innovated in the course of DT. This gap becomes more significant, considering numerous enterprises still struggle to transform their business models (Caputo et al., 2021). In this way, Gebauer et al. (2020) introduced the 'digital paradox' "which means that they invest in digital offerings, but struggle to achieve the expected revenue growth despite the proven growth potential of digital technologies."

In general, a BMI comprises a number of components aggregated into business model dimensions. The literature consists of over 70 semantically-different components forming 2–12 dimensions in business models (Clauss, 2017; Clauss et al., 2021; Teece, 2010). For the objective of the study, the business model definition provided by Teece (2010) is used: "A business model articulates the logic, the data, and other evidence that support a value proposition for the customer, and a viable structure of revenues and costs for the enterprise delivering that value." It should be noted that these business model dimensions form unique configurations of a firm rather than being separate from each other (Kulins et al., 2016). Any change to one dimension entails modular changes to the other dimensions (Foss & Saebi, 2016). BMI aims to configure novel business models or reconfigure the ones currently used (Clauss et al., 2019; Foss & Saebi, 2016). BMI complements the process/product innovation by taking a universal perspective toward the advanced potentials in the most important dimensions of a business (Massa et al., 2016). In addition, BMI attempts to discover novel business practices seeking to produce new value-creation processes, new worth propositions, and novel cost and revenue streams (Teece, 2018). Such processes have been made easy with innovative digital technologies (Trapp et al., 2017).

Due to the newly-provided digital environment, companies need to apply digital technologies and platforms to collect, integrate, and utilize data in a way that is well adapted to the platform economy (Petrakaki et al., 2018) and also explore new opportunities for progress to stay in market competition (Subramanian et al., 2011). Furthermore, some recently-conducted works have revealed that companies tend to use external venturing modes (Bagnoli et al., 2020) for the development of dynamic capacities (Enkel & Sagmeister, 2020). As a result, digitalization has been recognized as an entrepreneurial procedure (Autio et al., 2018; Henfridsson & Yoo, 2013) through which companies that seek DT purify formerly-effective BMs obsolete (Kiel et al., 2017; Tongur & Engwall, 2014) by using BMI, which is revolutionizing a large number of industries. The existing literature, in fact, indicates that by means of a proper BM, companies could benefit from the value potentially embedded in innovation (Chesbrough & Rosenbloom, 2002). For example, those companies that adopt digital technologies place great significance on data streams; they, therefore, use these technologies (rather than conventional BMs tools (Pigni et al., 2016)) as a support to their DT strategies (Zott et al., 2011). Thus, digital technologies have an inherent connection with strategic variations in BMs (Sebastian et al., 2020), which results in the development of novel BMs (Hess et al., 2016).

Recently, both academic and business communities have paid much consideration to topics such as DT and BMI. These concepts have some connections; however, they also have some differences from each other (Rof et al., 2020). For example, although the deployment of innovative DTL enhances the competitiveness of firms (Ferreira et al., 2019), this is not necessarily a BMI, even in cases where BMI might be one of the instruments or drivers the firm has used to reach that objective. The literature consists of many instances showing how digitalization has changed the entire rules of an industry or industries and how the business models have been innovated (Rachinger et al., 2019; Schallmo et al., 2019). Many studies have been carried out on DT in recent years due to its great potential influence on innovation processes, services, and BMs (Appio et al., 2018). The literature has succeeded in creating a link between DT and business models (Goerzig & Bauernhansl, 2018; Alberti-Alhtaybat et al., 2019); however, further research is required to clarify the role this DT can play in the BMI domain Schallmo et al. (2019), understanding the impact of digitalization on BMI (Rachinger et al., 2019), and finding out the best ways business models could be merged with DT (Müller et al., 2018). Higher education institutions (HEIs) have their special characteristics; however, they might encounter challenges similar to those faced by the more "regular" business sectors (Kaplan & Haenlein, 2016).

Although the BM concept has been mostly implemented from the perspective of private firms, HEIs have slowly, but systematically adopted business practices (Abdelkafi et al., 2018). Nevertheless, various scholars have recently concentrated on the way the BM concept could be applied to educational institutions (Posselt et al., 2019). This is the case despite the literature lacking inclusive research regarding BMs and BMI and their implication in the HEI, contrary to many studies already conducted on BMs' relation with the region of business. As DT is a continuing procedure at the present time, conventional HEIs have difficulty managing existing businesses; meanwhile, they are doing some practices not to become "the dinosaurs of the education area" (Kaplan & Haenlein, 2016). The continuous development of digital technologies causes opportunities and challenges, which can alter the HEIs' functioning externally (e.g., social networks) and internally (e.g., virtual campus). This also reveals a gap in capacities and resources for managing this digital transition and the generation of tensions that should be well addressed if HEIs expect to make appropriate decisions to survive in the future.

Due to the significance of DT and BMI to HEIs, as well as the absence of study into this issue in the higher education region, the current paper is aimed at exploring the most important challenges that may arise during the DT process for BMI in the context of HEIs and also determining the way HEIs assess such challenges regarding their influence and the change that may occur to HEIs' BMI in this procedure. Investigating this intersection of DT, BMI, and HEIs is the contribution of the present paper with considering the existing literature; two of the three axes are more focused. The objectives set for the current study entail answering the ensuing research questions:

RQ1: How do HEIs understand DT?

RQ2: What are the key DT challenges for BMI from the perspective of HEIs?

As much attention has been attracted recently to the link between DT and BMI in HEIs and its practical importance to these institutes, this study attempts to investigate the current knowledge regarding the DT of BMI. In this process, this paper uses the effectiveness and flexibility of IFSs to configure a new integrated framework that can assess the MADA problem on IFSs (which were selected because of their flexibility and efficiency). In addition, this study uses the new methodology of the IF-weighting technique with the use of RS for subjective and MEREC for objective to calculate the criteria weights. ARAS is also used as an effective approach to managing the MADA problems. Therefore, the current paper developed the IF-MEREC-RS-ARAS framework in order to evaluate the major DT challenges for BMI in HEIs. To do so, the key outcomes of the developed framework are discussed as

- ☐ We identify the key DT challenges for BMI in the context of higher education institutions using a survey model using the literature and interviews with experts.

- We discuss an ample framework to assess and analysis the DT challenges for BMI from the perspective of HEIs with an integrated decision-support model.
- We present a weighting procedure with the IF-MEREC and IF-RS models to find the weights of DT challenges for BMI in the context of HEIs.
- The IF-ARAS method is discussed using the IF-MEREC-RS to rank the HEIs and consider the DT challenges for BMI in the context of HEIs.

The paper is arranged as follows. A literature review on the DT challenges for BMI from the perspective of HEIs is given in Section 2. In Section 3, the developed IF-MEREC-RS-ARAS method is introduced. Section 4 presented the case study. Section 5 gives experimental results, comparative and sensitivity discussions. Section 6 presented discussion, conclusion, practical and policy implications, study limitations, and future recommendations.

Literature review

Business model innovation

The BM is defined as a holistic structure of actions embedded within a value network containing several events, which is used for forming and capturing value (Zott et al., 2011; Massa et al., 2017). For instance, studies using the rational standing opinion have highlighted the rational design procedures and internal restraints as the BMI backgrounds (Zott & Amit, 2010; Wei et al., 2017). Studies conducted on the evolutionary learning vision have maintained that BMI is the outcome of a trial-and-error procedure and have concentrated on the impacts of learning and experimentation on this process (McDonald & Eisenhardt, 2020). In the meantime, cognitive observation advocates have asserted that the transformation of BMs is done based on the cognitive schema changes of managers (Martins et al., 2015). Despite the important role of such studies in enriching our current knowledge of BMI, there is still a lack of investigation concentrating on the exploration of BMI antecedents from the viewpoint of the business ecosystem while considering the stakeholders' role as a key component of the business ecosystem. Several studies have recently indicated the need for more research into the stakeholders' role in BMI due to the existence of evidence regarding the propagation and importance of business ecosystems (Spieth et al., 2016). However, there is still a need to clarify the way stakeholders affect the companies' BMI and how such impacts differ in case of different stakeholders.

BMI innovates the mechanisms of companies, such as assessment formation, delivery, and seizure, and aids them in convincing their consumers to recompense for that value and convert this into profits (Zott et al., 2011). In addition, BMI complements the conventional topics of procedure, product, and organizational invention (Olofsson et al., 2018). BMI also aids companies in creating and sustaining margins or development (Euchner & Ganguly, 2014). Digital technology is a megatrend that disrupts and rebuilds the prevailing business models by providing great business opportunities (Li, 2020). Today, many companies (regardless of the size, age, location, and corresponding industry) are attempting to adapt themselves to the external varying digital contexts to provide their services and products more flexibly (Olofsson et al., 2018). BMI also stimulates the shop entry of different companies with BMs using electronic platforms to provide a proper stage for interaction with customers (Mahajan et al., 2002). Meanwhile, the development of the commercial internet has resulted in numerous innovative methods for exchanging and transacting information, which have often been found to be more effective and/or efficient (McGrath, 2010). Digitalization has transformed industries and forced companies to reconsider their business models (Iansiti & Lakhani, 2014).

The literature consists of some studies into BMI drivers; however, it still lacks theoretical underpinning and empirical research in this regard (Foss & Saebi, 2016). The studies already conducted on issues related to BMI have been mostly developed in silos, indicating little cross-citation amongst the rivulets (Zott et al., 2011). In reverse, DT is not limited to a definite business or commercial division; it influences cross-departmental or cross-divisional functions that affect the business as a whole. Furthermore, outcomes and digital innovation processes have become less restricted; they involve collaborations/interactions among various stakeholders (Nambisan et al., 2017). For that reason, in the present era of digitalization, research into business models is required to highlight a system-level, general model (Zott & Amit, 2010) to reshape the fundamental appreciative of the combinational issues that lead to BMI.

According to Ferreira, Fernandes and Ferreira (2019), digitalization requires firms to rapidly adopt and implement the newest inventions and modify their digital structure in a way to adopt emergent DTLs (Warner & Wäger, 2019). Therefore, the business models of firms have encountered many challenges, mostly induced by disrupting innovators and digital technologies (Rachinger et al., 2019). There is an increasing trend in the volume of attention paid to the topic of BM (especially BMI); however, there is still a need for more empirical and conceptual research in this regard (Foss & Saebi, 2018). Recently, Foss and Saebi (2016) highlighted whether BMI is principally associated with best management or is rather an operational procedure. In the body of research in this domain, employees and managers are often discussed as either the parties who implement the prescribed BM or as parties that potentially show resistance to the BM acceptance and implementation. For example, according to Spieth et al. (2014), top managers must familiarize themselves with organizational procedures to achieve the sustenance of operational-level workers. Although BMI approval by middle executives is one of the most important issues that determines either the success or the failure of a BMI procedure (Spieth et al., 2014), it is still unclear how their practices contribute or influence such a procedure. As the BMI literature is still in its initial stages of development (Berends et al., 2016), qualitative works are required to examine new types of processes from the middle and lower stages in a firm (Heyden et al., 2017).

Digital transformation

The dawn of information and digital technologies, which was associated with the implementation of "information and communication technologies (ICT)" (Siemens, 2004) and the rise of innovative DTLs (Resnick, 2002), led to DT (Hanna, 2016). In companies, the technology-supported DT is accompanied by the utilization of information and DTLs to influence various company features. For instance, novel technologies, such as smart phones, social media, IoT, big data, and cloud technologies, were used by companies (Fitzgerald et al., 2014) to improve their daily operations (Oestreicher-Singer & Zalmanson, 2013). Thus, such technologies successfully renovated how companies operate; this brought value and provided the stage for stakeholders to engage in various experiences.

Due to the rise of novel DTLs during the last decades, DT has become a focal point for both practitioners and scholars (Li et al., 2018). Technology-related organizational changes have been investigated in several studies considering technological enablers (Jarvenpaa & Ives, 1991), essential resources (Cha et al., 2015), and prospective returns (Ash & Burn, 2003). However, discussions made recently regarding the transformational effects of digital technologies have been supported by a perspective on the implementation of technologies in companies for the enhancement of business operations (Li et al., 2018). As a result, the relevant literature has emphasized the facilitation of business infrastructure, business application systems, and financial/organizational frameworks (Matt et al., 2015) in a way to diminish costs and recover the efficiency of optimized and automatized processes (Ash & Burn, 2003).

Several researchers have attempted to show how different industries and companies have implemented digital technologies and also to reveal their transformational impacts. According to Berman (2012), the major transformational opportunities are creating innovative business models, enhancing operational processes, and improving customers' experiences. Bharadwaj et al. (2013b) asserted that the DT era is an opportunity for firms to integrate IT strategy into their business strategies. These issues show how companies are rapidly getting engaged in the DT processes. Indeed, in the current digitalization age, DT is a routine agenda item in business meeting rooms. Therefore, DT has succeeded to create novel research interest across a variety of disciplines (Setia et al., 2013). This area has recently attracted a great deal of attention from academics, though the present paper showed that there is still scope for study into this part of the study. The small number of review papers published on DT, which were investigated in the current study (Besson & Rowe, 2012), shows that there is a confliction in defining and conceptualizing some fundamental components of the phenomenon, and there is a big uncertainty in defining the phenomenon, its drivers, characteristics, etc. The papers that have already reviewed the relevant literature have called for further research, particularly into the subject of the expansion and reconciliation of the DT literature (Besson & Rowe, 2012).

In this way, Westerman et al. (2014) discussed whether DT has the capacity to solve the business challenges arising in the digital age or should be considered another marketing buzz word. One of the most important challenges is the nonexistence of a widely-accepted definition of the fundamental elements. For example, a number of scholars tend to consider a slender technology-enabled change, namely the implementation of a novel ERP structure as DT, whereas DT, in some others' view, refers to a more evolutionary and radical process that occurs over time (Loebbecke & Picot, 2015). Although numerous scholars have associated DT with BMs and strategy, some other researchers have viewed it as a paradigm or as a procedure (Berman & Marshall, 2014).

DT and BMI in higher education institutions

DT (which has attracted much attention worldwide) uses technology to radically enhance companies' performance (Westerman et al., 2011). Managers in all types of industries implement new technologies (for instance, mobility, analytics, and smart embedded devices) to improve customers' relationships, value creation, and internal procedures (Riasanow et al., 2018). For the achievement of a fruitful DT, the most important factor is not necessarily using innovative technologies; rather, it is significant to recognize how a firm could benefit from the capacities provided by those technologies. Companies need to re-think customers' experiences, operational procedures, and BMs (Westerman et al., 2011). A review of the studies conducted on processes in BMI reveals that a "heterogeneous and siloed structure of BMI knowledge" exists (Wirtz & Daiser, 2018). In addition, the literature has concentrated too much on operating models; as a consequence, firms have encountered many challenges when struggling to succeed in the novel digitalized setting (Falque & Ward, 2017). These challenges could be discussed in terms of strategy, people, and management (Demil et al., 2015; Hess et al., 2016). Executives are required to be well-informed about the opportunities provided by the transformation of BM in the perspective of DT (Chen et al., 2022; Heredia et al., 2022; Lyu et al., 2022; Peng & Tao, 2022). To realize such ends, the current business management students should be focused on and provided with the essential knowledge in the present digital era (Fichman et al., 2014); thus, the academic community is responsible for finding out the best way to achieve this. However, based on previous findings (Loebbecke & Picot, 2015), the existing literature and HEIs still lack evidence to understand BMs from the DT perspective. The outcome of such a condition is the graduation of students who are not trained to face future challenges appropriately, especially at the strategic level (Snihur et al., 2021).

More recent research has argued that DT is something deeper than the mere electrification of existing processes using digitization; this phenomenon needs to holistically change and innovate companies' business models (Verhoef et al., 2021). According to Verhoef et al. (2021), DT is a firm-wide process that alters the logic behind the value creation and capture with the help of DTLs. If a firm arranges for a platform where the value proposition is the facilitation of the transactions among the otherwise independent actors (Cennamo, 2019), companies tend to rely upon network effects (Katz & Shapiro, 1985). For instance, a group of customers may be able to jointly negotiate better prices from a certain provider if their number rises. Digital advertisement and promotion could become even more significant because younger people tend to spend a lot of time online (McPhillips & Merlo, 2008). Through the digital interface procedures with consumers and customer products, much data could be achieved, which can be applied to product advances or personalized marketing actions (Chen et al., 2012). The impacts of digital technologies upon distribution channels are revealed by considering internet-only players, e.g., Amazon and eBay. The direct network impacts come to exist with the increase of the value proposition that takes place if more users join an ecosystem (Dou et al., 2012). In a recent study, Matarazzo et al. (2021) showed that DT in the value proposition dimension is able to support omni-channel marketing and delivery for digital offerings.

In this regard, some studies recently conducted on digital BMs and digital BMI (Richter et al., 2017) have revealed that the latter needs some critical organizational changes. The recent literature has also confirmed the existence of a connection between DT and business model design in certain setups. Li (2020) analyzed the ways digital technologies can modify business models in creative industries. Only in recent years has the research carried out in the European context focused further on the analysis of the elements of technology-motivated and digital BMI. According to Fichman et al. (2014), the concentration of a set upon DT and BM should be a topic connected to the discovery, development, diffusion, and BMI effects. Westerman (2018) defines DT as the implementation of technology intending to enhance business performance. The dynamic capabilities required for DT were analyzed in Warner and Wäger's (2019) study. Their study did not analyze the nature of BMI in more detail; however, the authors asserted that all the DT of all executives in their case assessment complicated renewing strategically the BMs. In the same sense, Hess et al. (2016) maintained that a key consequence of DT is creating a novel business model. However, Kane et al. (2015) believed that DT has no role in technology implementation; rather, it is dependent on the digital strategy taken into action by business leaders. According to Fitzgerald et al. (2014), DT refers to the implementation of DTLs that aid a business in enhancing the customers' experience, developing innovative and appropriate business models, and streamlining business processes. Gebauer et al. (2020) determined three steps for the conversion of digital aids into revenue enrichments in the B2B business. The main step involves augmenting the products with software; the second step involves solving more complicated customer problems using software solutions; and finally, at the last step, digital platforms are utilized to store and integrate data regarding customers' manufacturing systems. Likewise, Garzella et al. (2021) confirmed that digitalization causes an increase in the connection points and interfaces with the companies' external stakeholders (e.g., customers), thereby stimulating BMI. According to Verhoef et al. (2021), those businesses that follow DT tend to use BMI.

However, with the advent of the digital era, companies face a growing imperative to embrace digital technologies and platforms to collect, integrate, and leverage data efficiently (Petrakaki et al., 2018). Adaptability to the platform economy has become a crucial factor for businesses to not only thrive in the current digital landscape but also discover new opportunities for progress and maintain competitiveness in the market (Subramanian et al., 2011). Higher education institutions possess unique characteristics that distinguish them from other sectors. Nevertheless, they are not immune to challenges commonly experienced by conventional business sectors (Kaplan & Haenlein, 2016). While the business model concept has predominantly been applied within private firms, higher education institutions have gradually and deliberately embraced business practices (Abdelkafi et al., 2018). However, in recent times, scholars have increasingly focused on exploring how the business model concept can be applied to educational institutions (Posselt et al., 2019). This holds true even though there is a lack of comprehensive research on business models and business model innovation, specifically in the context of higher education institutions. In contrast to the numerous studies conducted on the relationship between business models and the business domain, there is a notable gap in the literature regarding their implications for higher education institutions.

Given the importance of digital transformation and business model innovation in higher education institutions, coupled with the lack of research in this specific area, the primary objective of this paper is to investigate the key challenges that may arise during the digital transformation process for business model innovation within higher education institutions. Additionally, this study aims to examine how higher education institutions assess these challenges in terms of their impact and the resulting changes to their business model innovation. The present paper contributes to the existing literature by investigating the intersection of digital transformation, business model innovation, and higher education institutions. While the literature has primarily focused on two of these three axes, this study aims to address the research gap and explore all three dimensions. The objectives of this study are centered around answering the following research questions: How do higher education institutions perceive and understand digital transformation? What are the primary challenges of digital transformation for business model innovation in higher education institutions? Therefore, we identify the major digital transformation challenges for business model innovation in higher education institutions by utilizing a survey model incorporating insights from the literature and expert interviews. In addition, we present a comprehensive framework that enables the assessment and analysis of digital transformation challenges in the context of business model innovation within higher education institutions.

The above-presented discussions and review of the existing literature conducted in the present study resulted in the recognition of DT challenges for BMI from the perspective of HEIs (Cozzolino et al., 2018; Heider et al., 2021). These challenges include building novel digital capabilities related to new technology (r_1), process and structure changes in cost and resistance (r_2), uncertainty about new offerings due to evolving students' preferences (r_3), lack of clear and standardized processes and protocols regarding the management of digital technologies (r_4), A “24-h-accessibility” syndrome (r_5), lack of “doing it all digital mentality” (r_6), new partners for new relationships (r_7), technical and service limitations to expand the offering (r_8), self-limited regional focus due to traditional offering (C_9), user infoxication and spamming (r_{10}), lack of definition of a clear and global social media strategy due to decentralization (r_{11}), reduction of old sources of revenues (r_{12}), difficult capture of new sources of revenues (r_{13}), face global competition (r_{14}), “free” business model (r_{15}), cost escalation and technological dependence (r_{16}), and reduction of old sources of costs (r_{17}).

The proposed IF-MEREC-RS-ARAS approach

Definition 1 (Atanassov, 1986). An IFS α on $Y = \{y_1,\ y_2,\ \ldots,\ y_n\}$ is given by

$$\alpha = \{\ \langle y_i,\ \mu_\alpha(y_i),\ \nu_\alpha(y_i)\rangle\ \ :\ y_i \in Y\},\tag{1}$$

where $\mu_\alpha : Y \to [0,\ \ 1]$ and $\nu_\alpha : Y \to [0,\ \ 1]$ show the membership degree and non-membership degree of y_i to α in Y, with the condition

$$0 \le \mu_\alpha(y_i) \le 1,\ 0 \le \nu_\alpha(y_i) \le 1 \text{ and } 0 \le \mu_\alpha(y_i) + \nu_\alpha(y_i) \le 1,\ \forall\ y_i \in Y.\tag{2}$$

The intuitionistic index of an element $y_i \in Y$ to α is defined by $\pi_\alpha(y_i) = 1 - \mu_\alpha(y_i) - \nu_\alpha(y_i)$ and $0 \le \pi_\alpha(y_i) \le 1,\ \ \forall\ y_i \in Y$.

For simplicity, Xu (2007) characterized the intuitionistic fuzzy number (IFN) $\zeta = (\mu_\zeta, \nu_\zeta)$ which holds $\mu_\zeta, \nu_\zeta \in [0,1]$ and $0 \le \mu_\zeta + \nu_\zeta \le 1$.

Definition 2 (Xu et al., 2015). Consider $\zeta_j = (\mu_j,\ \nu_j), j = 1(1)n$, be IFN. Therefore,

$$\mathbb{S}\left(\zeta_j\right) = \frac{1}{2}\left(\left(\mu_j - \nu_j\right) + 1\right), \hbar\left(\zeta_j\right) = \left(\mu_j + \nu_j\right),\tag{3}$$

are the score and accuracy values, respectively.

Consider $\zeta_1 = (\mu_1,\ \nu_1)$and $\zeta_2 = (\mu_2,\ \nu_2)$ two IFNs. To relate the IFNs, we get

If $\mathbb{S}(\zeta_1) > \mathbb{S}(\zeta_2)$, then $\zeta_1 > \zeta_2$,

If $\mathbb{S}(\zeta_1) = \mathbb{S}(\zeta_2)$,then if $h(\zeta_1) > h(\zeta_2)$, then $\zeta_1 < \zeta_2$; if $h(\zeta_1) = h(\zeta_2)$, then $\zeta_1 = \zeta_2$.

Definition 4 (Xu, 2007): Let $\zeta_j = (\mu_j,\ \nu_j), j = 1(1)n$ be IFNs. Then, IFWAO and IFWGO are defined as

$$IFWA_w(\zeta_1, \zeta_2, \ldots, \zeta_n) = \underset{j=1}{\overset{n}{\oplus}} w_j\zeta_j = \left[1 - \prod_{j=1}^{n}\left(1 - \mu_j\right)^{w_j},\ \prod_{j=1}^{n}\nu_j^{w_j}\right],\tag{4}$$

$$IFWG_w(\zeta_1, \zeta_2, \ldots, \zeta_n) = \underset{j=1}{\overset{n}{\otimes}} w_j\zeta_j = \left[\prod_{j=1}^{n}\mu_j^{w_j},\ 1 - \prod_{j=1}^{n}(1 - \nu_j)^{w_j}\right],\tag{5}$$

where $w_j = (w_1, w_2, \ldots, w_n)^T$ is a weight set of $\zeta_j,\ \ j = 1(1)n$, with $\sum_{j=1}^{n} w_j = 1, w_j \in [0,\ 1]$.

In addition, an extended decision-making methodology, i.e., IF-MEREC-RS-ARAS, is proposed in this section. ARAS uses the optimal degree to attain prioritization. This method has several benefits, of which the key items are: 1) it is directly and proportionally related to attribute weights (Mishra et al., 2021b), 2) it can offer effective solutions to complex problems (Mishra et al., 2020), 3) it assesses several options or choices in some simple and direct steps by comparing their performance to the selected evaluation criteria that have already attained results of sensibility, suitability, and comparative accuracy (Zavadskas and Turskis, 2010). The steps involved in the IF-MEREC-RS-ARAS procedure are explained as follows:

Step 1: Make a “linguistic decision matrix (LDM)”.

MCDM generally focuses on marking out an optimal choice from m options $H = \{hei_1, hei_2, \ldots, hei_m\}$ over a criterion set $R = \{r_1, r_2, \ldots, r_n\}$. Form a team of experts $D = \{d_1, d_2, \ldots, d_l\}$ to find suitable option(s). Let $T = (\xi_{ij}^{(k)})_{m\times n}$ be LDM offered by DEs, in which $\xi_{ij}^{(k)}$ entails the linguistic rating of an option hei_i over attribute r_j given by k^{th} expert.

Step 2: Estimation of weight (λ_k) of DEs

For the estimation of DEs' weights, their significance degrees are primarily considered as linguistic ratings (LRs) and then expressed using IFNs. If $d_k = (\mu_k, \nu_k)$ is an IFN, the k^{th} DE's weight will be evaluated as follows:

$$\lambda_k = \frac{1}{2}\left(\frac{\mu_k(2 - \mu_k - \nu_k)}{\sum_{k=1}^{l}[\mu_k(2 - \mu_k - \nu_k)]} + \frac{l - \rho_k + 1}{\sum_{k=1}^{l}(l - r_k + 1)}\right),\tag{6}$$

where $\lambda_k \ge 0$ and $\sum_{k=1}^{l}\lambda_k\ = 1$ and ρ_k denotes the rank of each DE, $k = 1,2,3,\ldots, l$.

Step 3: Make the "aggregated IF-DM (A-IF-DM)"

In this way, the LDM should be integrated into A-IF-DM. Accordingly, the IFWA (or IFWG) is used, and then the A-IF-DM is $Z = (z_{ij})_{m\times n} = (\mu_{ij}, \nu_{ij})$, where

$$z_{ij} = \left(\mu_{ij}, \nu_{ij}\right) = IFWA_{\lambda_k}\left(\xi_{ij}^{(1)}, \xi_{ij}^{(2)}, \ldots, \xi_{ij}^{(l)}\right) \text{ or } IFWG_{\lambda_k}\left(\xi_{ij}^{(1)}, \xi_{ij}^{(2)}, \ldots, \xi_{ij}^{(l)}\right) \quad (7)$$

Step 4: Computation of weight using IF-MEREC-RS

This paper does not suppose that all of the criteria are equally important. Assume that $w = (w_1, w_2, \ldots, w_n)^T$ is the weight of the criterion set with $\sum_{j=1}^{n} w_j = 1$ and $w_j \in [0, 1]$. In such state, the weights of the criteria are calculated by combining the subjective and objective weights.

Case I: Determination of objective weights by the method of IF-MEREC

To determine the criteria's objective weights, MEREC (Mishra et al. 2022) is extended under the IFS condition. In the following, the procedure of the MEREC is presented by

Step 4a: Normalize the A-IF-DM.

This step involves using a simple linear normalization to scale the elements of the A-IF-DM and produce the normalized A-IF-DM $\mathbb{N} = (\varsigma_{ij})_m \times n$. If r_b denotes the beneficial set and r_n stands for the non-beneficial set, then Eq. (8) is applied to the normalization:

$$\varsigma_{ij} = \left(\overline{\mu}_{ij}, \overline{\nu}_{ij}\right) = \begin{cases} \xi_{ij} = \left(\mu_{ij}, \nu_{ij}\right), & j \in r_b, \\ \left(\xi_{ij}\right)^c = \left(\nu_{ij}, \mu_{ij}\right), & j \in r_n. \end{cases} \quad (8)$$

Step 4b: Assess the IF-score matrix (IF-SM).

The IF-SM $\Omega = (\eta_{ij})_m \times n$ of each IFN ς_{ij} is computed using Eq. (9) (Rani and Mishra, 2021) as follows:

$$\eta_{ij} = \frac{1}{2}\left(\left(\overline{\mu}_{ij}\right) - \left(\overline{\nu}_{ij}\right) + 1\right). \quad (9)$$

Step 4c: Calculate the overall performance of options.

The normalized ratings achieved from the step 4b make sure that the smaller ratings of η_{ij} obtain greater performance ratings. Eq. (10) is applied to this computation:

$$S_i = ln\left(1 + \left(\frac{1}{n}\sum_j \left|ln\left(\eta_{ij}\right)\right|\right)\right). \quad (10)$$

Step 4d: Find the performance of options by removing each attribute.

Let S_i' stand for the overall performance of the i^{th} option concerning the removal of the j^{th} attribute. The computations at this step are done using Eq. (11) as follows:

$$S_{ij}' = ln\left(1 + \left(\frac{1}{n}\sum_{k, k\neq j} \left|ln(\eta_{ik})\right|\right)\right). \quad (11)$$

Step 4e: Calculate the sum of absolute deviations.

Let V_j be the impact of removing j^{th} attribute. Eq. (12) can be applied to find the V_j as

$$V_j = \sum_i \left|S_{ij}' - S_i\right|. \quad (12)$$

Step 4f: Determine the final criteria weights.

In Eq. (13), w_j^o signifies the j^{th} criterion's weight. This equation calculates the w_j^o value as follows:

$$w_j^o = \frac{V_j}{\sum_{j=1}^{n} V_j}. \quad (13)$$

Case II: Estimate the subjective weight with the IF-ranking sum (RS) model.

The process of the IF-RS model offers the ranking values for selected criteria. The expression to evaluate weight is given by

$$w_j^s = \frac{n - r_j + 1}{\sum_{j=1}^{n}(n - r_j + 1)}, \quad (14)$$

where w_j^s stands for the weight of j^{th} attribute, n signifies the number of attributes, and r_j represents the rank of attribute, j = 1,2,3,. . .,n.

Case III: Combined weight of criteria.

For achieving the combined weight, DE uses both IF-MEREC and IF-RS models as

$$w_j = \gamma w_j^o + (1 - \gamma) w_j^s \quad (15)$$

where $\gamma \in [0, 1]$ is a precision factor.

Step 5: Determine the "optimal performance rating (OPR)"

The OPR of each option can be determined as follows:

$$\mathbb{R}_0 = \begin{cases} \max \zeta_{ij}, & j \in r_b \\ \min \zeta_{ij}, & j \in r_n. \end{cases} \quad (16)$$

Step 6: Create the weighted normalized A-IF-DM (WNA-IF-DM)

The WNA-IF-DM $\mathbb{N}_{\widehat{w}} = (\tilde{\varsigma}_{ij})_m \times n$ is assembled as below:

$$\tilde{\varsigma}_{ij} = \left(\tilde{\mu}_{ij}, \tilde{\nu}_{ij}\right) = \bigoplus_{j=1}^{n} w_j\, \varsigma_{ij} = \left(1 - \prod_{j=1}^{n}\left(1 - \overline{\mu}_{ij}\right)^{w_j}, \prod_{j=1}^{n}\left(\nu_{\widehat{ij}}\right)^{w_j}\right). \quad (17)$$

Step 7: Determine the IF-score values

From Eq. (3), the IF-score rating of WNA-IF-DM $\mathbb{N}_w = (\tilde{\varsigma}_{ij})_m \times n$ are computed by

$$\mathbb{S}(\tilde{\varsigma}_{ij}) = \frac{1}{2}\left(\left(\tilde{\mu}_{ij} - \tilde{\nu}_{ij}\right) + 1\right) \quad i = 1(1)m, j = 1(1)n. \quad (18)$$

Step 8: Evaluate the "overall performance degree (OPD)" and "utility degree (UD)"

The OPD of each option can be estimated using the formula as

$$\Upsilon_i = \sum_{j=1}^{n} \mathbb{S}(\tilde{\varsigma}_{ij}), \; i = 1(1)m. \quad (19)$$

To choose a suitable option, it is not only essential to analyze the best-ranked option but also important to assess the OPD of obtained choices over the most desirable option. In this way, the UD Q_i of each optionhei_i is obtained as

$$Q_i = \frac{\Upsilon_i}{\mathbb{R}_0}; \; i = 1(1)m. \quad (20)$$

Step 9: Select the best option

The largest value of Q_i of each option hei_i is the appropriate one as

$$\Upsilon^* = \{\Upsilon_i | \; \max_i Q_i; \; i = 1(1)m\}, \quad (21)$$

where Υ^* is the optimal option.

Case study

The current study was conducted mainly to identify, assess, and analyze the major challenges of DT for BMI in the context of HEIs. Data required for the purpose of this research were collected in different phases. In the first phase, a comprehensive survey approach using interviews with experts and current literature. In this regard, 39 challenges are identified using current literature; in the next phase, a questionnaire is designed to be sent to experts to evaluate and select the challenges. To explore DT through the theoretical framework of challenges for BMI in the HEI context, this article used a multiple-case study approach to gather the required data by holding 11 semi-structured interviews with the participating experts. Remember that such a level of depth was not achievable by holding structured interviews since such interviews typically involve the delivery of predefined responses, and also, they are not flexible enough to ask potential probing questions (Easterby-Smith et al. 2021). Likewise, unstructured interviews were also avoided because of the predefined purpose of the current study. As noted earlier, this paper aimed to find out the DT challenges for BMI in the context of HEIs. As a result, the interviews followed a loose framework of topics extracted from the existing literature; thus, they did not adhere to the unstructured interview format that is relatively spontaneous and open, where the interviewer is typically left with no general guidelines in mind (Blumberg et al. 2014). Accordingly, this study preferred to conduct semi-structured interviews using a topic guide comprising a list of questions linked to various overarching topics that arose from the frame of reference for the present study. This type of interview helped to cover the areas identified in the frame of reference. In addition, it helped the authors have a deeper understanding of the potential themes for the analysis, for example, how companies create dynamic capacities for the innovation of their business models for DT and the potential challenges that may be faced with in this process. In addition, semi-structured interviews helped make the answers comparable, with room for asking supplementary follow-up questions from the respondents (Easterby-Smith et al. 2021). The questions included open questions in order to motivate the respondents to explain their experience with the DT process. As noted earlier, 11 semi-structured interviews were held through six HEIs, with 55−75 min in length. The authors took a number of measures to avoid biases throughout the data-gathering process. First, the themes of the interview guide were developed in advance, and the questions asked were designed in a way that was free from personal beliefs. Second, questions that might touch upon sensitive information (e.g., budget targets or financial rewards) were avoided. The reason for such avoidance was that sensitive questions may result in a reluctance to answer or lead to bias (Saunders et al., 2012). Finally, as the respondents were dispersed geographically, all of the interviews were held online, for example, via Skype or other tools based on the interviewees' convenience. For the purpose of confidentiality, the institution names and personal names were replaced with an assigned institution number, and an accompanying alphabetical letter was also allocated to each interviewee. The interviews were held with managers who had insight into digital initiatives and adequate knowledge regarding the digital strategies of their respective firms. The interview partners were chosen carefully considering the sampling method. The results of this phase of the interview found 20 main challenges that were important for digital transformation for BMI in the context of HEIs. The results of this phase of the data collection are presented in the following sections.

Study results

In this study, an integrated decision-making framework with the IFSs, the MEREC, RS, and the ARAS called the IF-MEREC-RS-ARAS method is developed to analyze the selected challenges. The implementation of the IF-MEREC-RS-ARAS method is discussed as follows:

Steps 1−3: Table 1 displays the DEs and attributes' significance in terms of LRs. The DEs' weights are presented in Table 2 based on Eq. (6) and Table 1. Table 3 shows the LDM to assess each DT challenge for BMI in the HEIs context.

From Eq. (7), we create the A-IF-DM $\mathbb{Z} = (\xi_{ij})_m \times n$ for assessing the DT challenges for BMI in the perspective of HEIs and are provided in Table 4.

Step 4. To determine the objective weight using IF-MEREC, the overall performances of the options are obtained with Eq. (9) as S_1 = 0.418, S_2 = 0.413, S_3 = 0.416, S_4 = 0.404, S_5 = 0.458 and S_6 = 0.393.

Table 1
LRs of options over criteria by DEs.

LRs	IFNs
Extremely good (EG)	(0.95, 0.05)
Very very good (VVG)	(0.85, 0.10)
Very good (VG)	(0.80, 0.15)
Good (G)	(0.70, 0.20)
Slightly good (MG)	(0.60, 0.30)
Average (A)	(0.50, 0.40)
Slightly low (ML)	(0.40, 0.50)
Low (L)	(0.30,0.60)
Very very low (VL)	(0.20, 0.70)
Very low (VVL)	(0.10, 0.80)
Extremely low (EL)	(0.05, 0.95)

Then, Eqs. (10)-(13), the weight of the main DT challenges for BMI in the HEIs context (which are presented under the last column of Table 5).

Using Eq. (14), the subjective weight is obtained using the IF-RS model of each DT challenge for BMI in the context of HEIs and discussed in Table 6 and Fig. 1.

Using Eq. (15), the combined weight for $\tau = 0.5$ is presented in Fig. 1 and discussed as

w_j = (0.0564, 0.0645, 0.0516, 0.0649, 0.0590, 0.0747, 0.0586, 0.0414, 0.0757, 0.0684, 0.0318, 0.0380, 0.0558, 0.0365, 0.0760, 0.0685, 0.0782).

Fig. 1 displays the weights of different DT challenges for BMI in the context of HEIs to achieve the objective. Reduction of old sources of costs (r_{17}) with a weight value of 0.0782 has come out to be the most important DT challenge for BMI in the perspective of HEIs. The "Free" business model (r_{15}) with a weight value of 0.0760 is the second most DT challenge for BMI in the perspective of HEIs. Self-limited regional focus due to traditional offering (r_9) is third with a significance value of 0.0757, lack of "doing it all digital mentality" (r_6) with weight value 0.0747 has fourth most important DT challenges for BMI in the perspective of HEIs and others are considered crucial digital transformation challenges for BMI in the perspective of HEIs.

Step 5: Afterward, the OPR of options to use the DT challenges for BMI in the perspective of HEIs is determined using Eq. (16) as

$\mathbb{R}_0$ ={(0.707, 0.212, 0.081), (0.602, 0.295, 0.103), (0.661, 0.244, 0.095), (0.493, 0.397, 0.110), (0.723, 0.192, 0.085), (0.679, 0.237, 0.084), (0.554, 0.342, 0.105), (0.744, 0.183, 0.073), (0.719, 0.205, 0.076), (0.661, 0.255, 0.084), (0.678, 0.241, 0.081), (0.716, 0.203, 0.081), (0.631, 0.266, 0.103), (0.732, 0.184, 0.084), (0.663, 0.251, 0.086), (0.659, 0.249, 0.092), (0.576, 0.319, 0.105)},

Step 6: Using Eq. (17), the WNA-IF-DM is created and mentioned in Table 7.

Steps 7−9: Next, using Eqs. (12)-(19), we find the IF-score rating and OPDs of each HEI to assess the DT challenges for BMI from the perspective of HEIs, which are discussed in Table 8. By Eq. (20), the UD (Q_i) is found as Q_1 = 0.7810, Q_2 = 0.7816, Q_3 = 0.7692, Q_4 = 0.8019, Q_5 = 0.7138 and Q_6 = 0.8366. Based on the UD (Q_i), the prioritization of HEIs to assess DT challenges for BMI in the perspective of HEIs is $hei_6 \succ hei_4 \succ hei_2 \succ hei_1 \succ hei_3 \succ hei_5$, and thus, from Eq. (21), the HEI-VI (hei_6) is the optimal one with diverse digital transformation challenges for BMI in the context of HEIs.

Sensitivity investigation

This study also consisted of sensitivity over parameter γ, which is presented in this subsection. The variation of γ helps assess the approach's sensitivity, varying from objective to subjective weighting models.

Table 9 and Fig. 2 present the variation of prioritization of HEIs with diverse parameter γ values. With this evaluation, we find

Table 2
The DEs' weight for DT challenges for BMI in the context of HEIs.

DEs	d_1	d_2	d_3	d_4
LRs	Very good (0.80, 0.15)	Very very good (0.85, 0.10)	Extremely good (0.95, 0.05)	Good (0.70, 0.20)
Score values	0.840	0.8925	0.950	0.770
ρ_k	3	2	1	4
Weight	0.2217	0.2793	0.3376	0.1615

Table 3
The LDM by DEs to the DT challenges for BMI in the context of HEIs.

	hei_1	hei_2	hei_3	hei_4	hei_5	hei_6
r_1	(MG,G,ML,M)	(M,G,MG,M)	(M,VG,M,G)	(M,G,VG,G)	(ML,MG,L,M)	(MG,G,MG,M)
r_2	(M,M,ML,VL)	(MG,G,M,MG)	(M,M,MG,M)	(ML,ML,G,ML)	(M,G,M,ML)	(ML,G,MG,M)
r_3	(L,G,G,VG)	(M,L,ML,G)	(ML,M,VL,MG)	(MG,L,M,VG)	(ML,M,VL,M)	(G,ML,M,G)
r_4	(G,VL,M,L)	(L,L,ML,MG)	(G,L,ML,M)	(G,MG,L,VL)	(MG,L,L,G)	(VL,G,M,L)
r_5	(MG,M,G,G)	(MG,MG,L,M)	(VG,L,M,VG)	(M,VVG,G,G)	(ML,M,VL,MG)	(MG,VG,VL,ML)
r_6	(ML,MG,VL,M)	(G,VG,MG,M)	(G,MG,M,MG)	(ML,M,M,ML)	(ML,M,M,L)	(L,VG,MG,MG)
r_7	(G,ML,ML,L)	(ML,L,MG,M)	(M,G,M,ML)	(M,M,VL,ML)	(G,VL,M,ML)	(ML,M,L,M)
r_8	(G,M,VVG,VG)	(MG,L,M,MG)	(L,M,G,ML)	(MG,G,L,VL)	(G,G,ML,VG)	(VL,G,MG,MG)
r_9	(ML,M,VG,G)	(M,M,ML,G)	(MG,L,VG,MG)	(M,VVG,G,M)	(ML,G,VG,M)	(M,VG,G,VG)
r_{10}	(ML,ML,MG,G)	(G,M,MG,ML)	(M,MG,ML,MG)	(MG,G,M,VL)	(ML,M,L,VL)	(MG,VG,M,G)
r_{11}	(M,MG,ML,L)	(L,G,VG,M)	(VG,G,M,MG)	(M,MG,G,M)	(MG,M,L,VL)	(MG,M,VG,G)
r_{12}	(M,L,MG,ML)	(G,G,VG,M)	(L,G,M,MG)	(M,MG,M,MG)	(G,G,ML,VL)	(ML,MG,L,ML)
r_{13}	(MG,M,G,G)	(M,M,MG,ML)	(ML,M,ML,M)	(ML,G,M,VL)	(VG,G,ML,L)	(M,MG,L,ML)
r_{14}	(ML,M,G,MG)	(G,L,MG,MG)	(VL,G,MG,M)	(G,VVG,G,M)	(ML,MG,VG,VL)	(MG,VG,L,L)
r_{15}	(M,L,VVG,G)	(G,M,ML,VVG)	(ML,L,G,MG)	(MG,M,M,ML)	(MG,G,MG,M)	(M,VG,MG,M)
r_{16}	(MG,M,ML,VL)	(M,MG,G,VG)	(ML,MG,G,G)	(VG,M,ML,L)	(MG,M,ML,MG)	(MG,VG,MG,L)
r_{17}	(VG,ML,M,ML)	(VL,MG,ML,M)	(M,ML,M,MG)	(MG,L,M,VG)	(M,G,MG,L)	(M,ML,G,MG)

Table 4
A-IF-DM to the DT challenges for BMI in the context of HEIs.

	hei_1	hei_2	hei_3	hei_4	hei_5	hei_6
r_1	(0.561, 0.333, 0.105)	(0.598, 0.299, 0.103)	(0.644, 0.272, 0.085)	(0.707, 0.212, 0.081)	(0.452, 0.445, 0.103)	(0.617, 0.281, 0.102)
r_2	(0.426, 0.472, 0.102)	(0.602, 0.295, 0.103)	(0.536, 0.363, 0.101)	(0.525, 0.367, 0.108)	(0.554, 0.342, 0.105)	(0.581, 0.314, 0.104)
r_3	(0.661, 0.244, 0.095)	(0.462, 0.432, 0.106)	(0.411, 0.485, 0.104)	(0.549, 0.359, 0.092)	(0.390, 0.508, 0.102)	(0.567, 0.326, 0.106)
r_4	(0.463, 0.428, 0.109)	(0.393, 0.504, 0.103)	(0.478, 0.414, 0.107)	(0.493, 0.397, 0.110)	(0.461, 0.431, 0.108)	(0.492, 0.398, 0.110)
r_5	(0.631, 0.266, 0.103)	(0.499, 0.397, 0.104)	(0.613, 0.308, 0.079)	(0.723, 0.192, 0.085)	(0.411, 0.485, 0.104)	(0.555, 0.357, 0.087)
r_6	(0.427, 0.468, 0.105)	(0.679, 0.237, 0.084)	(0.595, 0.302, 0.102)	(0.464, 0.436, 0.100)	(0.450, 0.449, 0.101)	(0.627, 0.288, 0.085)
r_7	(0.473, 0.420, 0.107)	(0.470, 0.427, 0.103)	(0.554, 0.342, 0.105)	(0.397, 0.501, 0.103)	(0.476, 0.416, 0.109)	(0.417, 0.482, 0.101)
r_8	(0.744, 0.183, 0.073)	(0.496, 0.401, 0.103)	(0.533, 0.359, 0.108)	(0.501, 0.388, 0.111)	(0.645, 0.260, 0.095)	(0.570, 0.323, 0.107)
r_9	(0.648, 0.270, 0.082)	(0.510, 0.386, 0.104)	(0.630, 0.288, 0.082)	(0.699, 0.215, 0.086)	(0.669, 0.249, 0.083)	(0.719, 0.205, 0.076)
r_{10}	(0.532, 0.363, 0.105)	(0.574, 0.323, 0.104)	(0.518, 0.380, 0.102)	(0.555, 0.338, 0.107)	(0.371, 0.527, 0.102)	(0.661, 0.255, 0.084)
r_{11}	(0.473, 0.425, 0.103)	(0.657, 0.259, 0.084)	(0.659, 0.253, 0.088)	(0.605, 0.292, 0.103)	(0.425, 0.471, 0.104)	(0.678, 0.241, 0.081)
r_{12}	(0.475, 0.421, 0.103)	(0.716, 0.203, 0.081)	(0.549, 0.344, 0.106)	(0.547, 0.352, 0.101)	(0.556, 0.334, 0.111)	(0.436, 0.461, 0.103)
r_{13}	(0.631, 0.266, 0.103)	(0.522, 0.376, 0.101)	(0.446, 0.453, 0.101)	(0.513, 0.379, 0.108)	(0.603, 0.305, 0.092)	(0.458, 0.439, 0.103)
r_{14}	(0.577, 0.317, 0.105)	(0.561, 0.333, 0.106)	(0.554, 0.339, 0.108)	(0.732, 0.184, 0.084)	(0.613, 0.305, 0.082)	(0.564, 0.349, 0.086)
r_{15}	(0.663, 0.251, 0.086)	(0.609, 0.296, 0.095)	(0.536, 0.356, 0.109)	(0.510, 0.389, 0.101)	(0.617, 0.281, 0.102)	(0.641, 0.276, 0.083)
r_{16}	(0.454, 0.443, 0.103)	(0.659, 0.249, 0.092)	(0.621, 0.274, 0.105)	(0.542, 0.370, 0.088)	(0.512, 0.386, 0.102)	(0.639, 0.276, 0.084)
r_{17}	(0.558, 0.355, 0.087)	(0.446, 0.451, 0.104)	(0.493, 0.406, 0.101)	(0.549, 0.359, 0.092)	(0.576, 0.319, 0.105)	(0.573, 0.322, 0.106)

Table 5
The objective weight using IF-MEREC.

Criteria	(S'_{ij}) values						V_j	w_j^o
	hei_1	hei_2	hei_3	hei_4	hei_5	hei_6		
r_1	0.399	0.396	0.401	0.393	0.432	0.376	0.104	0.0474
r_2	0.389	0.397	0.395	0.383	0.439	0.374	0.125	0.0571
r_3	0.404	0.387	0.385	0.384	0.427	0.373	0.141	0.0640
r_4	0.392	0.381	0.391	0.380	0.433	0.368	0.156	0.0710
r_5	0.403	0.390	0.269	0.394	0.429	0.372	0.245	0.1116
r_6	0.389	0.401	0.399	0.378	0.432	0.377	0.127	0.0580
r_7	0.393	0.388	0.396	0.372	0.434	0.362	0.157	0.0715
r_8	0.408	0.390	0.395	0.381	0.444	0.374	0.110	0.0502
r_9	0.403	0.391	0.400	0.392	0.445	0.381	0.089	0.0403
r_{10}	0.397	0.395	0.393	0.384	0.425	0.379	0.128	0.0583
r_{11}	0.392	0.399	0.402	0.388	0.430	0.379	0.111	0.0505
r_{12}	0.393	0.402	0.396	0.384	0.439	0.364	0.124	0.0564
r_{13}	0.403	0.391	0.388	0.382	0.442	0.365	0.130	0.0593
r_{14}	0.400	0.394	0.396	0.394	0.442	0.373	0.103	0.0468
r_{15}	0.404	0.397	0.395	0.381	0.443	0.377	0.104	0.0474
r_{16}	0.391	0.400	0.400	0.383	0.436	0.377	0.114	0.0520
r_{17}	0.398	0.386	0.392	0.384	0.440	0.374	0.128	0.0584

Table 6
Weights of the DT challenges for BMI in the context of HEIs using IF-RS.

Criteria	d_1	d_2	d_3	d_4	Aggregated IFNs	Crisp values $\mathbb{S}(\tilde{\xi}_{kj})$	Rank of challenges	Weight (w_j^s)
r_1	M	H	M	ML	(0.554, 0.342, 0.105)	0.606	8	0.0654
r_2	H	MH	M	ML	(0.568, 0.328, 0.104)	0.620	7	0.0719
r_3	M	M	MH	L	(0.510, 0.388, 0.102)	0.561	12	0.0392
r_4	VH	MH	L	ML	(0.558, 0.353, 0.089)	0.602	9	0.0588
r_5	MH	ML	ML	L	(0.438, 0.460, 0.102)	0.489	17	0.0065
r_6	ML	MH	H	MH	(0.603, 0.293, 0.104)	0.655	4	0.0915
r_7	M	ML	M	H	(0.516, 0.381, 0.104)	0.567	11	0.0458
r_8	M	MH	M	L	(0.504, 0.394, 0.102)	0.555	13	0.0327
r_9	VH	M	MH	MH	(0.635, 0.279, 0.086)	0.678	1	0.1111
r_{10}	ML	VH	M	ML	(0.585, 0.331, 0.084)	0.627	6	0.0784
r_{11}	MH	L	ML	MH	(0.464, 0.433, 0.104)	0.516	16	0.0131
r_{12}	M	ML	M	MH	(0.493, 0.406, 0.101)	0.543	15	0.0196
r_{13}	ML	VH	ML	L	(0.547, 0.368, 0.085)	0.590	10	0.0523
r_{14}	M	H	L	ML	(0.500, 0.392, 0.108)	0.554	14	0.0261
r_{15}	M	MH	VH	L	(0.636, 0.283, 0.081)	0.676	2	0.1046
r_{16}	MH	M	H	M	(0.600, 0.297, 0.104)	0.651	5	0.0850
r_{17}	H	ML	H	MH	(0.619, 0.276, 0.106)	0.671	3	0.0980

prioritization of HEIs for DT challenges for BMI in the perspective of HEIs as $hei_6 \succ hei_2 \succ hei_4 \succ hei_1 \succ hei_3 \succ hei_5$ when $\gamma = 0.0$ with IF-RS model, $hei_6 \succ hei_4 \succ hei_2 \succ hei_1 \succ hei_3 \succ hei_5$ when $\gamma = 0.5$ with combined IF-MEREC-RS model and $hei_4 \succ hei_6 \succ hei_1 \succ hei_2 \succ hei_3 \succ hei_5$ when $\gamma = 1.0$with IF-MEREC model, which entails HEI-VI (hei_6) is at the optimal one for each value of γ, whereas hei_5 has the last one for $\gamma = 0.0$ to $\gamma = 1.0$. As a result, IF-MEREC-RS-ARAS was found adequately stable with many parameter values. Table 9 clarifies that the developed method can produce preference results of both stability and flexibility in different utility parameters. For MCDM procedures and decision-makers, this property is of high significance.

Comparative study

This section compares the results of IF-MEREC-RS-ARAS and those of another approach. To evaluate the efficiency of IF-MEREC-RS-ARAS, IF-TOPSIS (Mishra, 2016) and IF-WASPAS (Rani and Mishra, 2020) methods were used to assess their performance in handling the decision-making problem.

IF-WASPAS model

In the following, the IF-WASPAS method is described:

Steps 1−4: As the aforementioned model

Step 5: Utilize the WSM $\mathbb{C}_i^{(1)}$ and the WPM $\mathbb{C}_i^{(2)}$ratings in the following expression

$$\mathbb{C}_i^{(1)} = \overset{n}{\underset{j=1}{\oplus}} w_j \xi_{ij}. \tag{22}$$

$$\mathbb{C}_i^{(2)} = \overset{n}{\underset{j=1}{\otimes}} \xi_{ij}^{w_j}. \tag{23}$$

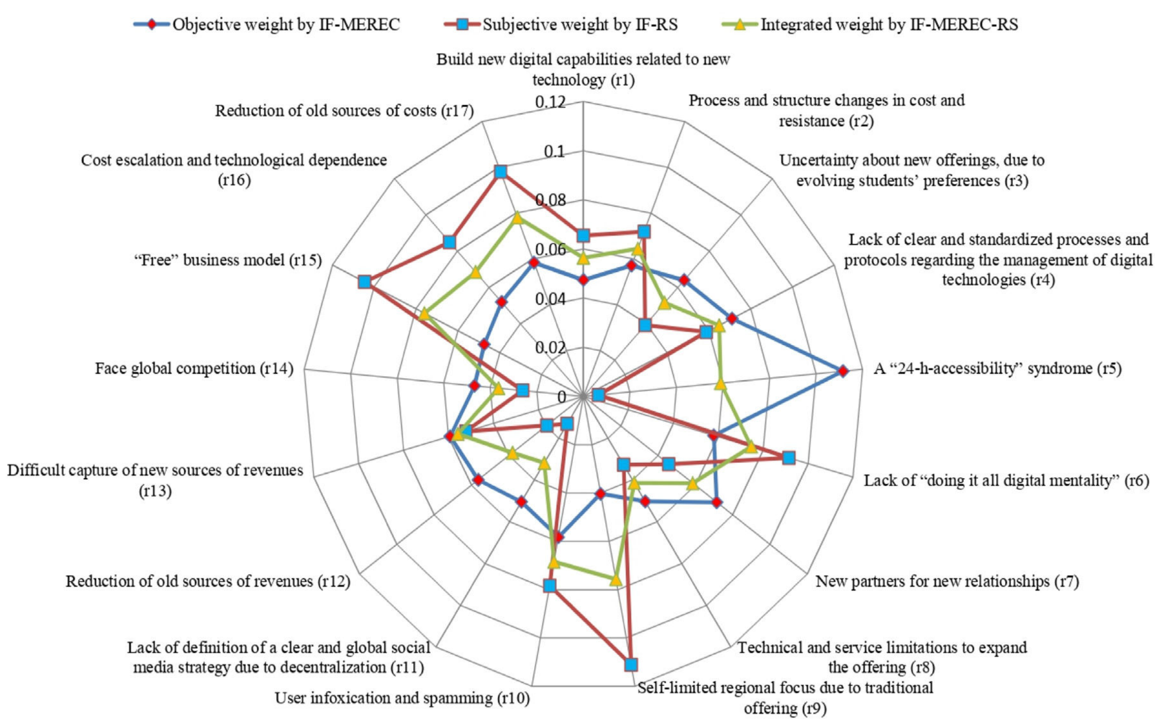

Fig. 1. Weight of the DT challenges for BMI in the perspective of HEIs.

Table 7
WNA-IF-DM for options over different challenges.

	$\mathbb{R}_0$	hei_1	hei_2	hei_3	hei_4	hei_5	hei_6
r_1	(0.067, 0.916, 0.017)	(0.045, 0.940, 0.015)	(0.050, 0.934, 0.016)	(0.057, 0.929, 0.014)	(0.067, 0.916, 0.017)	(0.033, 0.955, 0.011)	(0.053, 0.931, 0.016)
r_2	(0.058, 0.924, 0.018)	(0.035, 0.953, 0.012)	(0.058, 0.924, 0.018)	(0.048, 0.937, 0.015)	(0.047, 0.937, 0.016)	(0.051, 0.933, 0.016)	(0.055, 0.928, 0.017)
r_3	(0.054, 0.930, 0.016)	(0.054, 0.930, 0.016)	(0.031, 0.958, 0.011)	(0.027, 0.963, 0.010)	(0.040, 0.948, 0.011)	(0.025, 0.966, 0.009)	(0.042, 0.944, 0.014)
r_4	(0.043, 0.942, 0.015)	(0.039, 0.946, 0.014)	(0.032, 0.957, 0.012)	(0.041, 0.944, 0.014)	(0.043, 0.942, 0.015)	(0.039, 0.947, 0.014)	(0.043, 0.942, 0.015)
r_5	(0.073, 0.907, 0.020)	(0.057, 0.925, 0.018)	(0.040, 0.947, 0.013)	(0.055, 0.933, 0.013)	(0.073, 0.907, 0.020)	(0.031, 0.958, 0.011)	(0.047, 0.941, 0.012)
r_6	(0.081, 0.898, 0.021)	(0.041, 0.945, 0.014)	(0.082, 0.898, 0.021)	(0.065, 0.914, 0.020)	(0.046, 0.940, 0.015)	(0.044, 0.942, 0.014)	(0.071, 0.911, 0.018)
r_7	(0.046, 0.939, 0.015)	(0.037, 0.950, 0.013)	(0.037, 0.951, 0.012)	(0.046, 0.939, 0.015)	(0.029, 0.960, 0.011)	(0.037, 0.950, 0.013)	(0.031, 0.958, 0.011)
r_8	(0.055, 0.932, 0.013)	(0.055, 0.932, 0.013)	(0.028, 0.963, 0.009)	(0.031, 0.958, 0.010)	(0.028, 0.962, 0.010)	(0.042, 0.946, 0.012)	(0.034, 0.954, 0.011)
r_9	(0.092, 0.887, 0.021)	(0.076, 0.906, 0.018)	(0.053, 0.930, 0.017)	(0.072, 0.910, 0.017)	(0.087, 0.890, 0.023)	(0.080, 0.900, 0.020)	(0.092, 0.887, 0.021)
r_{10}	(0.071, 0.911, 0.018)	(0.051, 0.933, 0.016)	(0.057, 0.926, 0.018)	(0.049, 0.936, 0.015)	(0.054, 0.929, 0.018)	(0.031, 0.957, 0.012)	(0.071, 0.911, 0.018)
r_{11}	(0.035, 0.956, 0.009)	(0.020, 0.973, 0.007)	(0.033, 0.958, 0.009)	(0.034, 0.957, 0.009)	(0.029, 0.962, 0.009)	(0.017, 0.976, 0.006)	(0.035, 0.956, 0.009)
r_{12}	(0.047, 0.941, 0.012)	(0.024, 0.968, 0.008)	(0.047, 0.941, 0.012)	(0.030, 0.960, 0.010)	(0.030, 0.961, 0.009)	(0.030, 0.959, 0.010)	(0.021, 0.971, 0.007)
r_{13}	(0.054, 0.929, 0.017)	(0.054, 0.929, 0.017)	(0.040, 0.947, 0.013)	(0.032, 0.957, 0.011)	(0.039, 0.947, 0.013)	(0.050, 0.936, 0.014)	(0.034, 0.955, 0.011)
r_{14}	(0.047, 0.940, 0.013)	(0.031, 0.959, 0.010)	(0.030, 0.961, 0.010)	(0.029, 0.961, 0.010)	(0.047, 0.940, 0.013)	(0.034, 0.958, 0.008)	(0.030, 0.962, 0.008)
r_{15}	(0.079, 0.900, 0.020)	(0.079, 0.900, 0.020)	(0.069, 0.912, 0.020)	(0.057, 0.924, 0.019)	(0.053, 0.931, 0.016)	(0.070, 0.908, 0.022)	(0.075, 0.907, 0.018)
r_{16}	(0.071, 0.909, 0.020)	(0.041, 0.946, 0.014)	(0.071, 0.909, 0.020)	(0.064, 0.915, 0.020)	(0.052, 0.934, 0.014)	(0.048, 0.937, 0.015)	(0.067, 0.916, 0.017)
r_{17}	(0.065, 0.915, 0.021)	(0.062, 0.922, 0.016)	(0.045, 0.940, 0.015)	(0.052, 0.932, 0.016)	(0.060, 0.923, 0.017)	(0.065, 0.915, 0.021)	(0.064, 0.915, 0.021)

Table 8
OPD of HEIs to the DT challenges for BMI in the perspective of HEIs.

	$\mathbb{R}_0$	hei_1	hei_2	hei_3	hei_4	hei_5	hei_6
r_1	0.075	0.053	0.058	0.064	0.075	0.039	0.061
r_2	0.067	0.041	0.067	0.056	0.055	0.059	0.063
r_3	0.062	0.062	0.037	0.032	0.046	0.030	0.049
r_4	0.051	0.047	0.038	0.048	0.051	0.046	0.050
r_5	0.083	0.066	0.047	0.061	0.083	0.036	0.053
r_6	0.092	0.048	0.092	0.075	0.053	0.051	0.080
r_7	0.054	0.043	0.043	0.054	0.034	0.044	0.037
r_8	0.061	0.061	0.033	0.036	0.033	0.048	0.040
r_9	0.102	0.085	0.061	0.081	0.098	0.090	0.102
r_{10}	0.080	0.059	0.066	0.056	0.063	0.037	0.080
r_{11}	0.040	0.023	0.038	0.038	0.034	0.021	0.040
r_{12}	0.053	0.028	0.053	0.035	0.034	0.036	0.025
r_{13}	0.063	0.063	0.047	0.038	0.046	0.057	0.039
r_{14}	0.053	0.036	0.034	0.034	0.053	0.038	0.034
r_{15}	0.090	0.090	0.079	0.066	0.061	0.081	0.084
r_{16}	0.081	0.047	0.081	0.074	0.059	0.055	0.076
r_{17}	0.075	0.070	0.053	0.060	0.069	0.075	0.075
OPR	1.181	0.923	0.923	0.909	0.947	0.843	0.988
Utility degree	–	0.7810	0.7816	0.7692	0.8019	0.7138	0.8366
Ranking		4	3	5	2	6	1

Table 9
Prioritization outcomes of HEIs with different values of γ.

γ	hei_1	hei_2	hei_3	hei_4	hei_5	hei_6
γ = 0.0 (Subjective weight by IF-RS)	0.7853	0.7985	0.7798	0.7962	0.7463	0.8761
γ = 0.1	0.7843	0.7948	0.7775	0.7974	0.7394	0.8679
γ = 0.2	0.7834	0.7913	0.7753	0.7985	0.7327	0.8598
γ = 0.3	0.7825	0.7879	0.7732	0.7997	0.7263	0.8519
γ = 0.4	0.7818	0.7847	0.7711	0.8008	0.7200	0.8442
γ = 0.5 (Integrated method by IF-MEREC-RS)	0.7810	0.7816	0.7692	0.8019	0.7138	0.8366
γ = 0.6	0.7804	0.7787	0.7674	0.8030	0.7079	0.8291
γ = 0.7	0.7798	0.7759	0.7657	0.8040	0.7020	0.8218
γ = 0.8	0.7793	0.7732	0.7640	0.8051	0.6963	0.8145
γ = 0.9	0.7788	0.7706	0.7624	0.8062	0.6907	0.8073
γ = 1.0 (Objective weight by IF-MEREC)	0.7784	0.7682	0.7609	0.8072	0.6852	0.8002

Step 6: Find the *UD* of each HEI as follows:

$$\mathbb{C}_i = \lambda \mathbb{C}_i^{(1)} + (1-\lambda)\mathbb{C}_i^{(2)}, \tag{24}$$

where 'λ' means the decision strategy factor.

Step 7: Using the *UD* $(\mathbb{C}_i)$ to prioritize the alternatives.

Using Eq. (22)-Eq. (24), the *UD* of each HEI for DT challenges for BMI in the perspective of HEIs is found and mentioned in Table 10.

The priority order of options is $hei_6 \succ hei_4 \succ hei_2 \succ hei_1 \succ hei_3 \succ hei_5$. Thus, the higher education institution-VI (hei_6) option is the best one of the DT challenges for BMI in the perspective of HEIs.

The IF-TOPSIS method

The considered model has the following processes:

Steps 1–4: Follow the previous method

Step 5: Form the best and worst ratings

Here, the IF-IS (ϕ_j^+) and the IF- AIS (ϕ_j^-) are defined as follows:

$$\phi_j^+ = \{ \max_i \mu_{ij}, \text{ for } \textit{benefit criterion } r_b \; \min_i \nu_{ij}, \text{ for } \textit{cost criterion } r_n \tag{25}$$

$$\phi_j^- = \{ \min_i \mu_{ij}, \text{ for } \textit{benefit criterion } r_b \; \max_i \nu_{ij}, \text{ for } \textit{cost criterion } r_n. \tag{26}$$

Step 6. Compute the rating of similarity from IF-IS and IFA-IS

With the use of Mishra (2016), we calculate the degree weighted similarity$S(hei_i, \phi_j^+)$ among the options $hei_i\left(i = 1(1)m\right)$ and the IF-IS ϕ_j^+.

$$S\left(hei_i, \phi_j^+\right) = \frac{1}{2}\sum_{i=1}^{n} w_j \left[\left|\mu_{\xi_{ij}} - \mu_{\phi_j^+}\right| + \left|\nu_{\xi_{ij}} - \nu_{\phi_j^+}\right| + \left|\pi_{\xi_{ij}} - \pi_{\phi_j^+}\right|\right], \tag{27}$$

and the degree of similarity $S(hei_i, \phi_j^-)$ among the options $hei_i\left(i = 1(1)m\right)$ and the IFA-IS ϕ_j^- is given as follows:

$$S\left(hei_i, \phi_j^-\right) = \frac{1}{2}\sum_{i=1}^{n} w_j \left[\left|\mu_{\xi_{ij}} - \mu_{\phi_j^-}\right| + \left|\nu_{\xi_{ij}} - \nu_{\phi_j^-}\right| + \left|\pi_{\xi_{ij}} - \pi_{\phi_j^-}\right|\right]. \tag{28}$$

Step 7: Determine the "relative closeness coefficient (RCC)"

The RCC of each HEI over the IF-ISis given as

$$\mathbb{C}(hei_i) = \frac{S\left(hei_i, \phi_j^-\right)}{S\left(hei_i, \phi_j^+\right) + S\left(hei_i, e_j^-\right)}, \quad i = 1, 2, ..., m. \tag{29}$$

Step 8: Find the maximum ratings $\mathbb{C}(hei_k)$, among the values $\mathbb{C}(hei_i)$, $i = 1, 2, ..., m$. Thus, hei_k is the suitable one.

Step 9: End

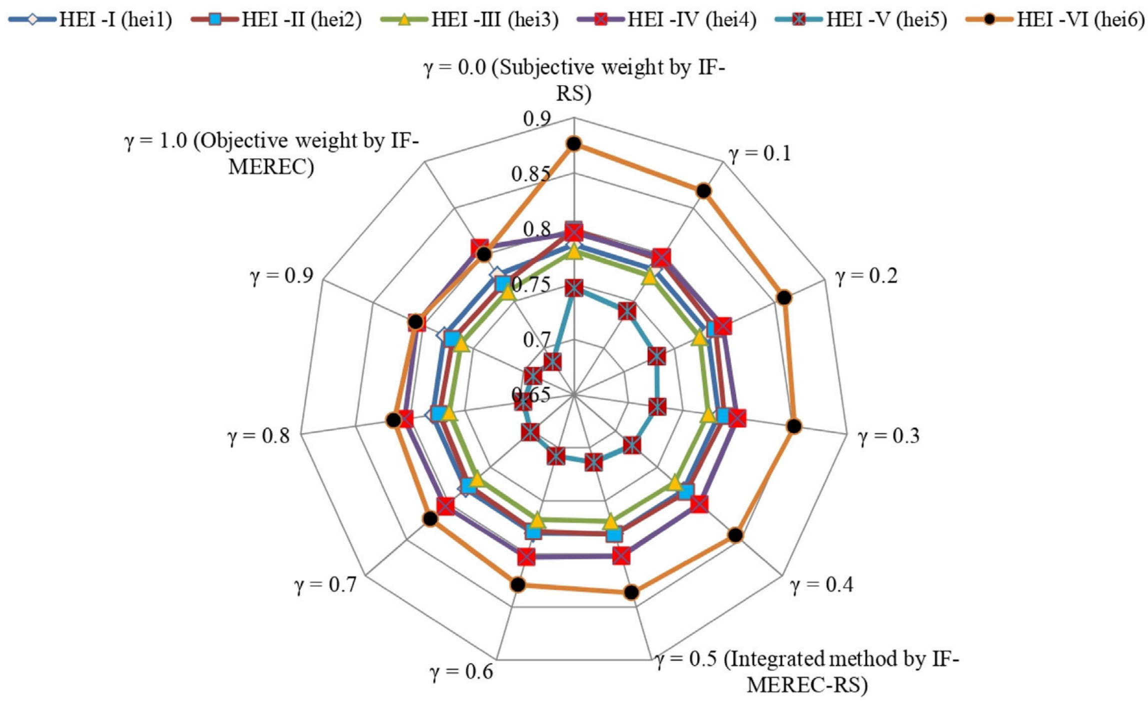

Fig. 2. Sensitivity of the UD values over the utility parameter γ.

Table 10
The *UD* of option for DT challenges for BMI in the context of HEIs.

options	WSM		WPM		UD ($\mathbb{C}_i$)	Ranking
	$\mathbb{C}_i^{(1)}$	$\mathbb{S}(\mathbb{C}_i^{(1)})$	$\mathbb{C}_i^{(2)}$	$\mathbb{S}(\mathbb{C}_i^{(2)})$		
hei_1	(0.561, 0.339, 0.099)	0.611	(0.543, 0.357, 0.100)	0.593	0.6020	4
hei_2	(0.561, 0.339, 0.100)	0.611	(0.545, 0.354, 0.101)	0.595	0.6032	3
hei_3	(0.555, 0.345, 0.100)	0.605	(0.546, 0.353, 0.101)	0.596	0.6006	5
hei_4	(0.571, 0.330, 0.099)	0.621	(0.553, 0.348, 0.099)	0.603	0.6118	2
hei_5	(0.526, 0.372, 0.102)	0.577	(0.509, 0.388, 0.103)	0.560	0.5688	6
hei_6	(0.590, 0.315, 0.094)	0.637	(0.576, 0.328, 0.096)	0.624	0.6308	1

By employing Eqs. (25)-(26), the IF-IS and IF-AIS of HEIs are computed as

ϕ_j^+ ={(0.707, 0.212, 0.081), (0.602, 0.295, 0.103), (0.661, 0.244, 0.095), (0.493, 0.397, 0.110), (0.723, 0.192, 0.085), (0.679, 0.237, 0.084), (0.554, 0.342, 0.105), (0.744, 0.183, 0.073), (0.719, 0.205, 0.076), (0.661, 0.255, 0.084), (0.678, 0.241, 0.081), (0.716, 0.203, 0.081), (0.631, 0.266, 0.103), (0.732, 0.184, 0.084), (0.663, 0.251, 0.086), (0.659, 0.249, 0.092), (0.576, 0.319, 0.105)},

ϕ_j^- ={(0.452, 0.445, 0.103), (0.426, 0.472, 0.102), (0.390, 0.508, 0.102), (0.393, 0.504, 0.103), (0.411, 0.485, 0.104), (0.427, 0.468, 0.105), (0.397, 0.501, 0.103), (0.496, 0.401, 0.103), (0.510, 0.386, 0.104), (0.371, 0.527, 0.102), (0.425, 0.471, 0.104), (0.436, 0.461, 0.103), (0.446, 0.453, 0.101), (0.564, 0.349, 0.086), (0.510, 0.389, 0.101), (0.454, 0.443, 0.103), (0.446, 0.451, 0.104)}.

From Eqs. (27)−−(29), the overall outcomes of the IF-TOPSIS model are given in Table 11.

From Table 11, hei_6 is the best higher education institution alternative, and prioritization ordering of technologies for assessing the digital transformation challenges for BMI in the context of HEIs is $hei_6 \succ hei_4 \succ hei_2 \succ hei_1 \succ hei_3 \succ hei_5$.

Next, the prioritization of options obtained by the IF-MEREC-RS-ARAS framework is similar to the IF-WASPAS (Mishra et al., 2020) and IF-TOPSIS (Mishra, 2016). Tables 8 10 and 11 show the prioritization of six HEIs of the DT challenges for BMI from the perspective of HEIs. From Tables 8 10 and 11, we catch that the optimal institution is HEI-VI (hei_6) of the DT challenges for BMI from the perspective of HEIs. Also, the *UD* of HEIs of the DT challenges for BMI in the perspective of HEIs is presented in Fig. 3. As aforesaid comparison, the IF-MEREC-RS-ARAS has the following merits:

- IF-WASPAS integrates IFWG and IFWA operators in order to aggregate *UD*, whereas ARAS employs the conception of ODs to attain preferences. ARAS has several advantages, of which the key items are as follows: 1) it has a direct and proportional association with DT challenges weights, 2) it can solve complex problems, 3) it takes some direct and simple phases to assess various options using their assessment by comparing with the selected attributes that have attained sensible, suitable, and relatively-accurate outcomes (Zavadskas and Turskis, 2010). As a result, the method introduced in this study enjoys a superior structure that can

Table 11
Ranking order of HEIs.

Options	$S(hei_i, \phi_j^+)$	$S(hei_i, \phi_j^-)$	$\mathbb{C}(hei_i)$	Ranking
hei_1	0.103	0.110	0.5162	4
hei_2	0.101	0.111	0.5223	3
hei_3	0.103	0.110	0.5160	5
hei_4	0.094	0.120	0.5610	2
hei_5	0.136	0.076	0.3588	6
hei_6	0.071	0.141	0.6647	1

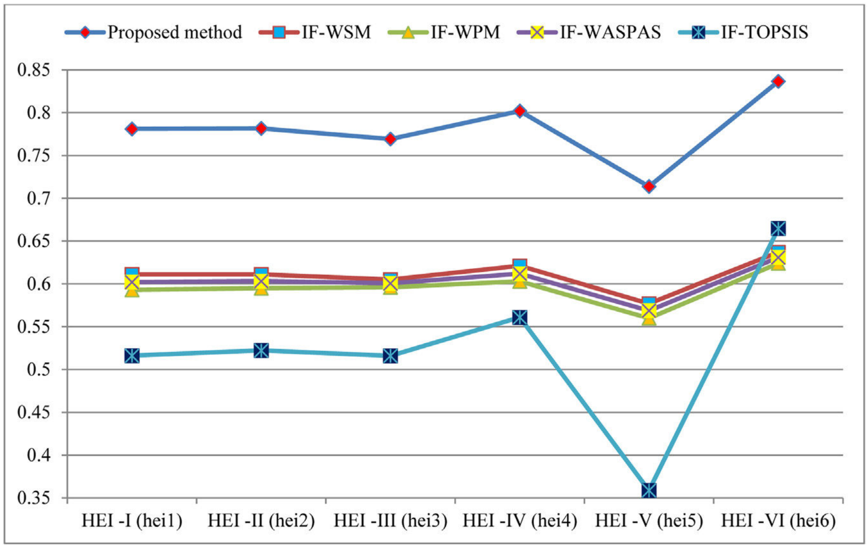

Fig. 3. Assessment of preferences of HEIs with diverse models.

accurately estimate the reference values for choosing the optimal option.

- MEREC calculates the objective weight, and IF-RS attains the subjective weight of the DT challenges for BMI in the HEIs context; this has been found to be a conventional tool with less complexity. In addition, in IF-TOPSIS and IF-WASPAS, the only objective weight of attributes is computed. This subjective and objective weighting association was considered with the help of IF-MEREC-RS, which showed that IF-MEREC-RS-ARAS was of higher reliability, practicality, and efficiency.

Discussion and conclusion

Digital transformation (DT) has recently provided many opportunities for companies to preserve their competitiveness in the current digital economy era. Many innovative technologies, namely, IoT, big data, and artificial intelligence, are (re)shaping the interconnections of value chains and customer interfaces, thereby driving innovation in BMs. In this logic, digitalization can be described as the implementation of DTLs with the goal of innovating a BM and providing new revenue streams and value-producing opportunities in industrial ecosystems. Though BMI has garnered a strong interest in the scientific literature, the state-of-the-art knowledge on digital technology-driven BMI is still very limited and fuzzy. Indeed, few empirical insights exist (as the extant literature is largely conceptual constructs), thus explaining why digital technology-driven BMI remains inadequately operationalized. To advance the body of knowledge on this topic, multidisciplinary research is needed to refine, broaden, and develop novel solutions that will guide digital innovation management practices. Yet, it is surprising to note that while the literature is rich in insights pertaining to information systems and technologies, there are very scant studies explaining digitalization's influence on BMI from a managerial standpoint. More importantly, digitalization is much more than just the instrumental application of various digital technologies. In fact, digital transformation shifts into a multifaceted phenomenon that causes a strategic rather than technical evolution of BM, whose components require a wider and deeper rethinking. Hence, the present special issue was commissioned to promote greater research and understanding of the intricate relationship between digital transformation and BMI by focusing on the application of managerial theories in empirical settings.

However, DT has been recently recognized as a new paradigm that companies are required to implement in order to benefit from competitive benefits in the present time. The great influence of DT, along with platform technologies, is being increasingly acknowledged by firms and organizations; however, it is still necessary to investigate the implications of DT on HEIs. In light of the DT dynamics, there is still a need to answer the question of how HEIs can better accomplish the shift toward newer competencies and the need for innovation presented by the emergence of DTLs. Therefore, to analyze, rank, and assess the key DT challenges for BMI in the context of HEIs, this paper is developed an integrated decision support model under IFSs with the IF-MEREC-RS and IF-ARAS models known as the IF-MEREC-RS-ARAS method. To rank the main DT challenges for BMI in the context of HEIs, the IF-MEREC-RS model is applied, and to prioritize the diverse HEIs to the assessment of the main DT challenges for BMI in the context of HEIs, the IF-ARAS model is presented. To validate the outcomes, a comparison with the IF-TOPSIS, IF-WSM, IF-WPM, and IF-WASPAS methods is presented.

Practical and policy implications

In recent years, numerous sectors have experienced digital transformation. However, the education industry is still in its nascent stages. Consequently, HEIs must establish business models that can effectively navigate a multifaceted value network. This network comprises both private and public stakeholders, with value intricately linked to sustainable development goals encompassing economic and social aspects. The presence of diverse stakeholder demands, needs, and values within public-private networks adds to the complexity that already exists within heavily bureaucratic organizational environments.

This empirical research carries numerous practical implications. The presented findings hold substantial value for the HEI involved and extend their relevance to other HEIs. They offer an insightful, in-depth analysis of the concept of digital transformation for business model innovation, making them highly illustrative and applicable across various contexts. The proposed method has the potential to serve as a collaborative exercise involving all stakeholders within the HEI. Through active participation, it can facilitate the establishment of a shared vision and a roadmap for innovating the business model in response to digital transformation. This knowledge can be of great use to policymakers, who can leverage it to design interventions that foster the digital transformation of HEIs within their regional or national ecosystems.

By aligning with policy goals such as enhancing education quality, inclusiveness, or efficiency, these interventions may take the form of direct subsidies or indirect incentives. It is also important to note that in the case of public HEIs, governments hold formal stakeholder positions within the governing bodies of these institutions, enabling them to act as agents of change and actively promote digital transformation. In their view on business model innovation and digital transformation, managers of HEIs elaborated on the importance of driving change within the entire organization.

Innovating the business model for digital transformation is a process that is connected to various activities intertwined in the dynamic capability framework. With emerging technologies and an ever-changing business environment, logistics and transportation organizations have started building up capabilities for the ongoing change. Managers and strategists of HEIs to realize it as a tool for building up a digital strategy for their organization. As a successful business model innovation is connected to various organizational activities, the framework can help HEIs managers and strategists to understand the entire picture of this complex process.

By using the framework, HEIs managers can decide, evaluate, and prioritize different activities and make decisions regarding which areas need further funding, support, or expertise. HEI managers can leverage the comprehensive overview of the envisioned business model's desired future to develop precise digital transformation plans. These plans would concentrate efforts and enhance the commitment of various stakeholders involved. Adopting a strategic, long-term approach based on shared commitment would address the governance challenge commonly faced by public HEIs.

Policymakers can utilize the promotion of digital transformation plans as a means to guide HEI governance towards crucial public goals, thereby encouraging longer-term commitments and fostering alignment with desired outcomes. HEI managers can leverage the business model exercise to compare and benchmark new entrants, industry incumbents, and digital giants. By analyzing these benchmarks, they can infer the strategies employed by leading referents and, more importantly, draw conclusions about the desired business model they aim to achieve. These insights hold significant relevance, enabling HEI managers to prioritize digital transformation-derived experiments and initiatives effectively. This prioritization, in turn, accelerates the continuous process of BMI, propelling HEIs forward in their digital transformation journey.

Policymakers can be attentive or active drivers of such experiments to learn about BMI, with the aim of scaling up the developments to other HEIs in their systems or even transposing such learnings to other public institutions. As indicated by earlier research, BMI frequently arises from an unplanned process, particularly for average market players. However, our findings reveal that the HEI does not adopt a disciplined and systematic approach to BMI; rather, it engages in such efforts in response to the changes brought about and anticipated by DT. In this context, HEI managers individually construct their future business model, drawing heavily from their expertise and management positions. Although the envisioned business model is not formally agreed upon, it serves as a guide for their decision-making process.

Study limitations and future recommendations

This study acknowledges certain limitations that could serve as the foundation for future research. Recognizing that DT is an evolving field within both research and corporate practices, particularly in the context of HEIs, it is essential to acknowledge the nascent stage of this research and development domain. Encouragement is given for future investigations to adopt a longitudinal perspective, delving into the practical implications of how DT transforms business models within HEIs. Another limitation of this study is the lack of detailed descriptions and extensive case studies that explore the various paths of DT in depth. To provide a more comprehensive description, it is essential to include detailed objectives and steps involved in transformation activities and a comprehensive analysis of all enterprise architecture layers. Visualizing the effects of DT steps across these layers would enhance understanding the transformation process. Additionally, addressing the limitation of relying solely on a single case of transformation can be remedied by involving multiple higher education organizations. This expansion of case studies is deemed as one of the most significant future endeavors in the field. Implementing DT for BMI within the context of HEIs presents significant challenges. The early stages of this process often give rise to problems that, in turn, have negative consequences. Therefore, future research should focus on investigating the consequences of DT implementation for BMI in HEIs, encompassing areas such as lifestyle-changing lectures, global networking, and cost and benefit analyses associated with the adoption of DT for BMI. In this regard, researchers are encouraged to develop enabling tools and methodologies that can assist HEIs in effectively managing the changing phenomenon. These tools can help in formulating appropriate strategies and skills for human resources, infrastructure, and minimize the negative impacts of DT implementation for BMI in HEIs. HEIs should be prepared to adopt the DT for BMI in various domains, including policy, resources, programs, and digital technology. Some proposed research topics, among others, could include infrastructure and digital technology implementation in HEIs, pedagogical aspects of DT integration, students' acceptance and viability of DT, readiness to use DT within HEIs, changing demographics and its impact, complexity, and innovation in the context of DT, social aspects of DT implementation, organizational changes and innovations, development of hybrid programs integrating DT, and comprehensive integration of digital technology with the institutional structure. One potential limitation of this study relates to the study sample and context. Specifically, this study exclusively focuses on DT implementation for BMI in HEIs. Consequently, future studies could explore digital transformation at other educational levels to provide a more comprehensive understanding of its impact. One potential limitation of this study relates to the methodology employed for analyzing the framework. Specifically, this study utilized a decision support system incorporating decision-making methods and fuzzy sets models. While this approach offers valuable insights, it is important to acknowledge that alternative methods, such as structural equation modeling (SEM), could be employed in future studies to explore the relationships between the identified challenges in the framework. Another limitation of this study is related to the proposed method. In this study, we utilized the integration of ARAS, MEREC, and RS based on intuitionistic fuzzy sets (IFSs). However, it is worth mentioning that there exist several other MCDM methods, such as MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique), GAIA (Generalized Annotated Impact Assessment), MABAC (Multi-Attributive Border Approximation area Comparison), EDAS (Evaluation based on Distance from Average Solution), UTASTAR (UTilités Additives et Multiplicatives), WASPAS (Weighted Aggregated Sum Product Assessment), MOORA (Multi-Objective Optimization on the Basis of Ratio Analysis), MUltiple-TRIangles ScenarioS (MUTRISS), among others, which future papers can consider to analyze the challenges of DT implementation for BMI in HEIs using different types of fuzzy sets. Exploring these research areas will contribute to advancing the understanding of DT implementation for BMI in HEIs, equipping institutions with the necessary knowledge and strategies to navigate the challenges and leverage the benefits of this transformative process.

CRediT authorship contribution statement

Gen Li: Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Xixiang Sun:** Project administration, Resources, Software. **Min Ye:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Abbas Mardani:** Supervision, Validation, Visualization.

Appendix: Study abbreviations

Keywords	Descriptions
DT	Digital Transformation
HEIs	Higher Education Institutions
MEREC	Method based on the Removal Effects of Criteria
RS	Rank Sum
IFSs	Intuitionistic Fuzzy Sets
BMI	Business Model Innovation
Dt	Digital Technology
ARAS	Additive Ratio Assessment
MADA	Multi-Attribute Decision Analysis
ICT	Information and Communication Technologies
BM	Business Model
IFWAO	Intuitionistic Fuzzy Weighted Averaging Operator
IFWG	Intuitionistic Fuzzy Weighted Geometric Operator
LDM	Linguistic Decision Matrix
OPR	Optimal Performance Rating
OPD	Overall Performance Degree
UD	Utility Degree
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
WASPAS	Weighted Aggregated Sum Product Assessment
WSM	Weighted Sum Model
WPM	Weighted Product Model
MACBETH	Measuring Attractiveness by a Categorical-Based Evaluation Technique
GAIA	Generalized Annotated Impact Assessment
MABAC	Multi-Attributive Border Approximation Area Comparison
EDAS	Evaluation based on Distance from Average Solution
UTASTAR	UTilités Additives et Multiplicatives
MOORA	Multi-Objective Optimization on the Basis of Ratio Analysis
MUTRISS	MUltiple-TRIangles ScenarioS

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